Pen-based Haptic Virtual Environment

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Abstract: This paper describes about development of a pen-based force display and its application to direct manipulation of free-form surface. We have developed a 6 degree-of-freedom force reflective master manipulator which has pen-shaped grip. The system employs two 3 degree-of-freedom manipulators. Both end of the pen are connected to these manipulators. By this mechanism, the hardware of the force display is small and light weighted. The performance of the force display is exemplified in interactive deformation of free-form surface. The surface is deformed like an embossed metal plate.

Keywords: force display, pen-based, haptic, free-form surface,

1. Introduction

Design of 3D shapes is difficult if we use conventional input devices such as keyboards or mice. Spatial input device is inevitable for direct manipulation of geometric models[1][2]. In the real world, we feel reaction force from materials in modeling solid objects. Force feedback plays important roles in manipulation of virtual objects[3]. Takahashi, Kanai, and Morisawa developed a glove-like force feedback device for deformation of free-form surface[4].

Virtual world technology usually employs glove-like tactile input devices. Users feel troublesome when they put or off these devices. If the glove is equipped with force feedback device, the problem is much severe. This disadvantage obstructs practical use of force displays. This paper describes method of implementation of force display without glove-like device. A pen-based force display is proposed as an alternative device. We have developed a 6 degree-of-freedom force reflective master manipulator which has pen-shaped grip. Users are familiar to a pen in their everyday life. Most of the human intellectual works are done with a pen. We use spatulas or rakes for modeling solid objects. These devices have stick-shaped grips similar to a pen. In this aspect, the pen-based force display is easily applied to design of 3D shapes. This paper proposes a method of deformation of free-form surface. The surface is deformed like an embossed metal plate.

2. A Pen-based Force Display

Human hand has an ability of 6 degree-of-freedom motion in 3D space. If we build a 6 degree-of-freedom master manipulator which has serial joints, each joint must support the weight of upper joints. This characteristics leads large hardware of the manipulator. We use parallel mechanism in order to reduce size and weight of the manipulator. The pen-based force display employs two 3 degree-of-freedom manipulators. Both end of the pen are connected to

these manipulators. Total degree-of-freedom of the force display is 6. Three degree-of-freedom force and 3 degree-of-freedom torque are applied at the pen. Overall view of the system is shown in Figure 1. Each 3 degree-of-freedom manipulator is composed of pantograph link. By this mechanism, the pen is free from the weight of the actuators.

Figure 2 shows a diagram of mechanical configuration of the force display. Joints MA1, MA2, MA3, MB1, MB2, and MB3 are equipped with DC motors and potentiometers. Other joints move passively. The position of joint A and B are measured by potentiometers. Three dimensional force vector is applied at the joint A and B. The joint A determines the position of the pen point, and the joint B determines the orientation of the pen. Working space of the pen point is a spherical volume whose diameter is 44 cm. The rotational angle around the axis of the pen is determined by the distance between the joint A and B. A screw motion mechanism converts rotational motion of the pen into transition of the distance between the joint A and B.

Applied force and torque at the pen are illustrated in Figure 3. **FA** indicates a force vector applied at the joint A. **FB** indicates a force vector applied at the joint B. If **FA** and **FB** are the same vectors, translational force is generated(See Figure 3(a)). If direction of **FA** and **FB** are reverse, torque around the yaw axis or the pitch axis is generated(See Figure 3(b),(c)). If **FA** and **FB** are opposite, torque around the roll axis is generated by the screw motion mechanism(See Figure 3(d)).

The pen is equipped with a push button. Function of the pen in virtual environment is activated by pushing the button.

3. System Configuration of Pen-based Virtual Environment

The hardware configuration of the overall system is indicated in Figure 4. The host computer is SGI IRIS Indigo (R3000, Entry). A V25 board computer has A/D (analog to digital) convertors and PIO (parallel input/output unit). V25 is an intel 8086 compatible micro processor. Joint angles of the force display are acquired by A/D convertors. Accuracy of position sensing of the pen point is 2 mm. Motor torque is generated by PWM (Pulse Width Modulation) amplifier. The maximum generated force at the pen is 500gf. The weight of the pen (220gf) is compensated. The V25 board computer is connected to the host computer by RS232C.

The host computer executes following processes:

1) Calculation of the position and orientation of the pen
2) Handling of the geometric model of free-from surface
3) Collision detection and calculation of reaction force
4)Graphics drawing

Sampling rate of the force display and update rate of graphics is 10Hz.

4. Deformation of Free-form Surface

As an example of application of the force display to design of 3D shapes, we implemented a deformation algorithm of free-form surface. The deformation is caused by direct motion of the pen. If the user pushes or pulls the surface while pushing the button on the pen , it deforms. The user feels reaction force while the surface is deforming. This action is similar to embossing a metal plate.

Figure 1. Overall view of the system

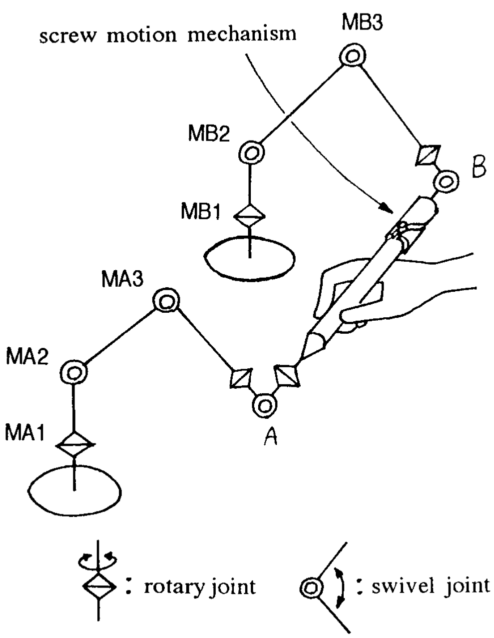


Figure 2. Mechanical configuration of the force display

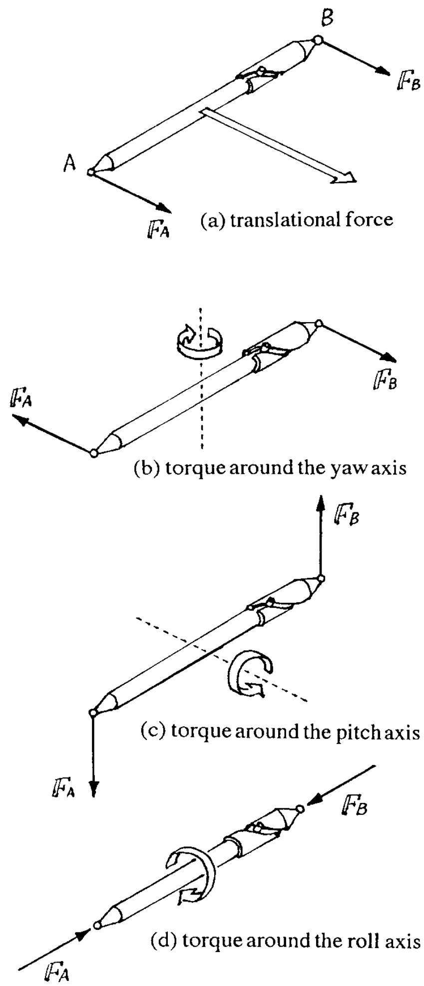


Figure 3. Applied force

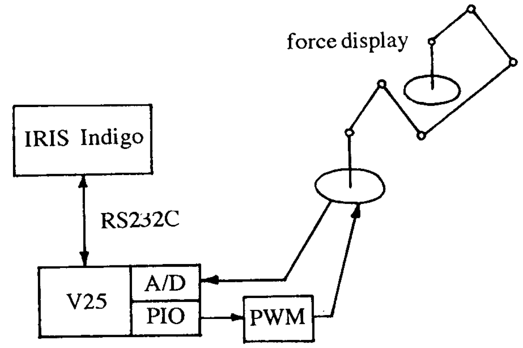
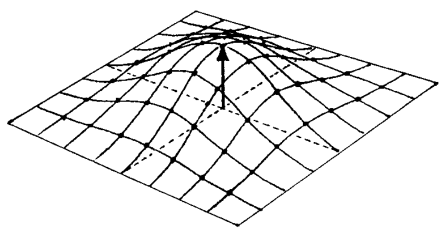
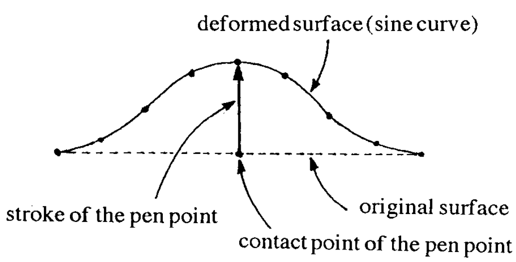


Figure 4. Hardware configuration of the system



(a) 3D shape of deformation pattern



(b) central section of deformation pattern

Figure 5. The method of deformation

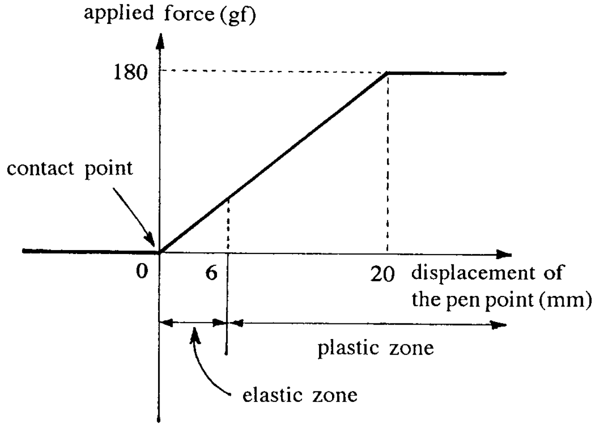
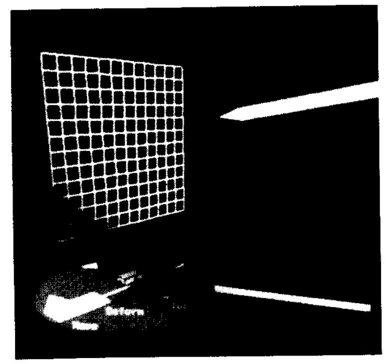
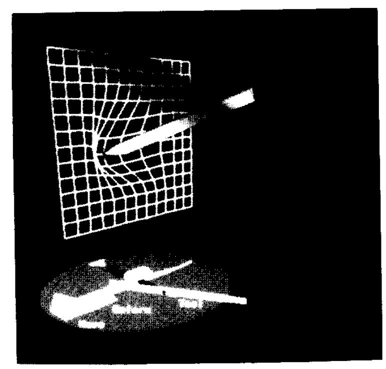


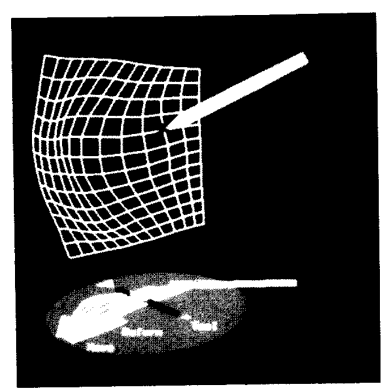
Figure 7. Relationship between displacement of the pen point and applied force



(a) original surface



(b) deformed surface by a single user action



(c) deformed surface by complex user actions

Figure 6. Examples of deformation

The method of deformation is illustrated in Figure 5. Figure 5(a) shows a 3D shape of the deformation caused by a single user action. Deformed shape is generated by sine curves. Figure 5(b) shows a central section of (a). When the user releases the button, the deformation stops. If the user pushes or pulls the surface again, deformation pattern shown in Figure 5(a) is overlapped. Figure 6 shows examples of user actions.

Reaction force is applied to the pen while the surface is deforming. The force vector is vertical to the original surface. Figure 7 indicates the relationship between displacement of the pen point and applied force. Elastic zone is set at the contact point by which the user feels presence of the surface. If the user pushes the pen against the reaction force, the surface is deformed. Applied reaction force increases proportional to the displacement of the pen point.

5. Design Tools for 3D Shapes

Two design tools for 3D shape modeling are implemented in the pen-based virtual environment. The first one is "move mode" for moving position and orientation of the surface. The move mode is selected by a toggle switch. The second tool is selection of the deformation area Deformation area is changed by a slide volume. Figure 8 shows these switches. Pushing the toggle switch, the pen point turns into a robot hand(Figure 9). If the user fixes the pen point at the surface and push the button on the pen, the surface moves corresponding with the pen. If the user operates the slide volume, shape of the pen point changes. A large pen point indicates wide deformation area(Figure 10). A sharp pen point indicates small deformation area(Figure 11).

6. Conclusions

The 6 degree-of-freedom pen-based force display is developed and performance of the device is exemplified in interactive deformation of free-form surface. Unlike glove-like tactile input devices, the pen-based force display does not require users to fit the device to their hand. It neither require calibrations. For this advantage, the pen-based force display is easily combined to everyday work space.

Pen-based operation is currently a major issue in the field of user-interface. Some pen-based OS are proposed and actually used. Our device can easily combine those environments. Future work of our research will be development of pen-based haptic user environment such as 3D widgets or new design methods for 3D shapes.

5. Acknowledgments

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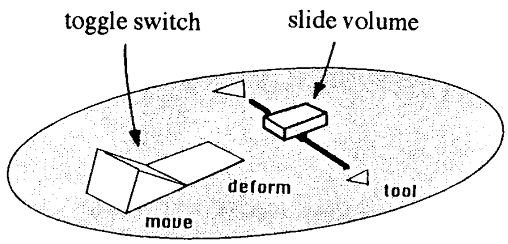

Figure 8. Switches for design tools

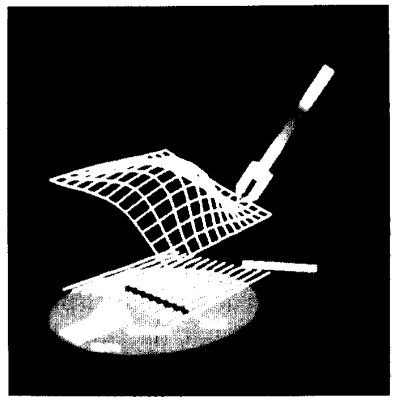

Figure 9. The "move mode"

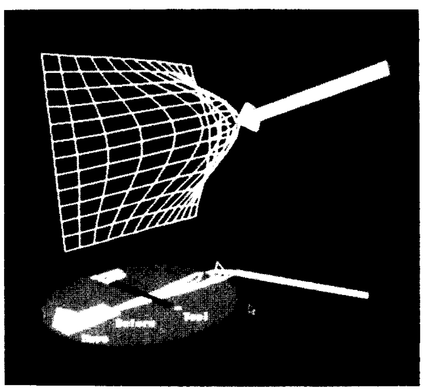

Figure 10. Wide deformation area

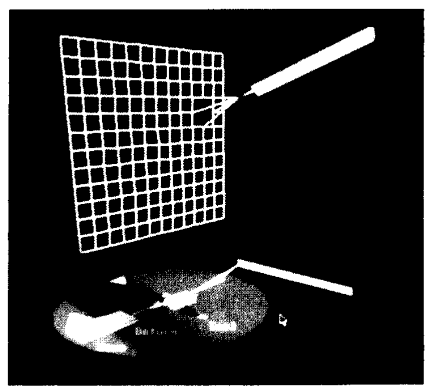

Figure 11. Small deformation area